US010233726B2

(12) **United States Patent**
He et al.

(10) **Patent No.: US 10,233,726 B2**
(45) **Date of Patent: Mar. 19, 2019**

---

(54) **PRESSURE DIFFERENTIAL DEVICE WITH CONSTANT PRESSURE DROP**

(71) Applicants: **Zhi Y. He**, Cypress, TX (US); **Madhawa Ratnayake**, Houston, TX (US); **Kun Yuan**, Houston, TX (US); **Carlos P. Izaguirre**, Houston, TX (US); **David Teale**, Spring, TX (US); **Darrin L. Willauer**, The Woodlands, TX (US)

(72) Inventors: **Zhi Y. He**, Cypress, TX (US); **Madhawa Ratnayake**, Houston, TX (US); **Kun Yuan**, Houston, TX (US); **Carlos P. Izaguirre**, Houston, TX (US); **David Teale**, Spring, TX (US); **Darrin L. Willauer**, The Woodlands, TX (US)

(73) Assignee: **BAKER HUGHES, A GE COMPANY, LLC**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 612 days.

(21) Appl. No.: **14/466,076**

(22) Filed: **Aug. 22, 2014**

(65) **Prior Publication Data**

US 2016/0053577 A1 Feb. 25, 2016

(51) **Int. Cl.**

E21B 34/10	(2006.01)
E21B 43/12	(2006.01)
E21B 41/00	(2006.01)

(52) **U.S. Cl.**

CPC ***E21B 34/101*** (2013.01); ***E21B 34/10*** (2013.01); ***E21B 34/102*** (2013.01); ***E21B 43/12*** (2013.01); *E21B 41/00* (2013.01)

(58) **Field of Classification Search**

CPC E21B 34/101; E21B 34/10; E21B 43/12; E21B 34/102

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,485,474 A *	12/1969	Baumann	F16K 1/54 251/121
3,693,732 A *	9/1972	Sabi	E21B 21/08 166/91.1
3,715,098 A *	2/1973	Baumann	F16K 47/04 251/121
3,880,399 A *	4/1975	Luthe	F16K 47/02 137/625.37
4,044,834 A *	8/1977	Perkins	E21B 21/08 166/370
5,123,436 A *	6/1992	Koechlein	G05D 16/0666 137/12
7,419,002 B2 *	9/2008	Dybevik	E21B 43/12 166/169

(Continued)

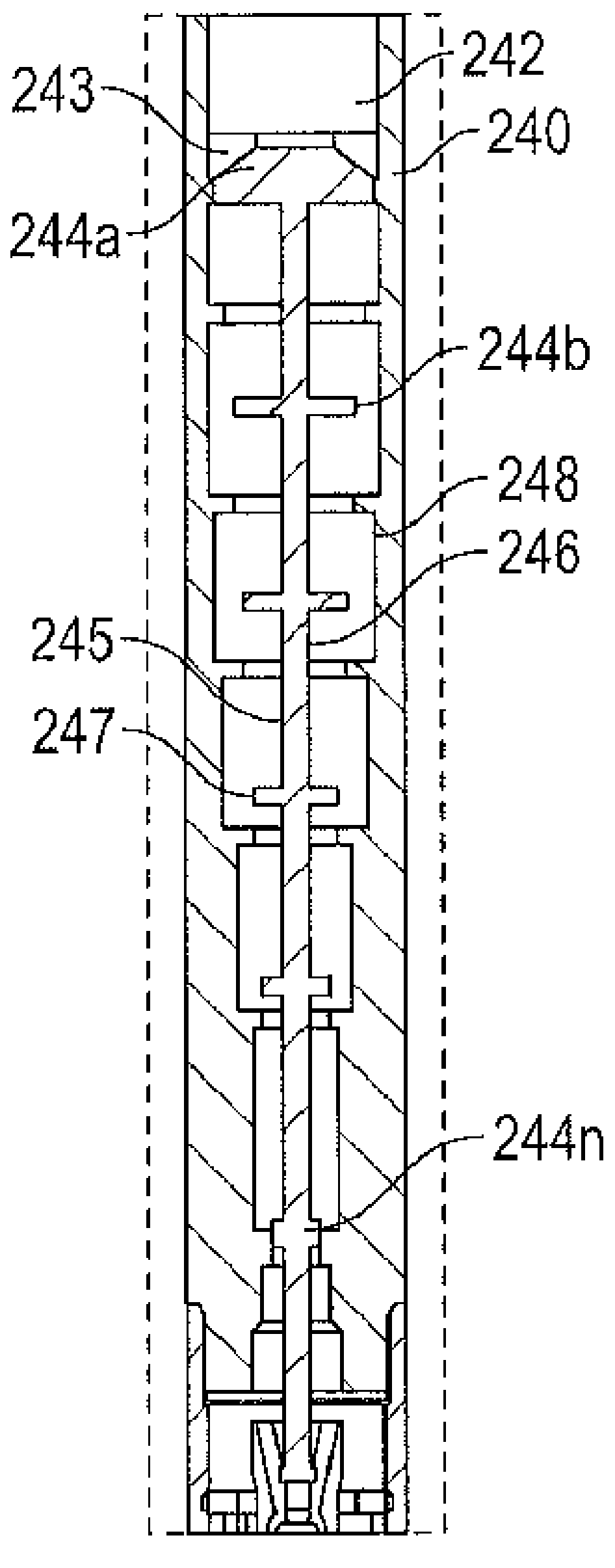
Primary Examiner — Nicole Coy

(74) *Attorney, Agent, or Firm* — Cantor Colburn LLP

(57) **ABSTRACT**

In one aspect, an apparatus for use in a wellbore is disclosed, including: an inlet; an outlet; and a variable flow restriction configured to provide a predetermined constant pressure drop between the inlet and the outlet in response to a range of inlet flow rates. In another aspect, a method for providing a fluid flow within a wellbore is disclosed, including: providing the fluid flow to an inlet; restricting the fluid flow to provide a predetermined constant pressure drop between the inlet and an outlet in response to a range of fluid flow rates; and providing the fluid flow to the wellbore from the outlet.

17 Claims, 3 Drawing Sheets



(56) References Cited

U.S. PATENT DOCUMENTS

8,069,921	B2 *	12/2011	Garcia	E21B 34/08 166/236
8,403,038	B2 *	3/2013	Russell	E21B 43/12 166/205
8,403,061	B2 *	3/2013	Russell	E21B 43/12 166/369
8,833,466	B2 *	9/2014	Zhou	E21B 34/08 166/319
2013/0019673	A1 *	1/2013	Sroka	E21B 49/08 73/152.55
2013/0068467	A1 *	3/2013	Zhou	E21B 34/08 166/369

* cited by examiner

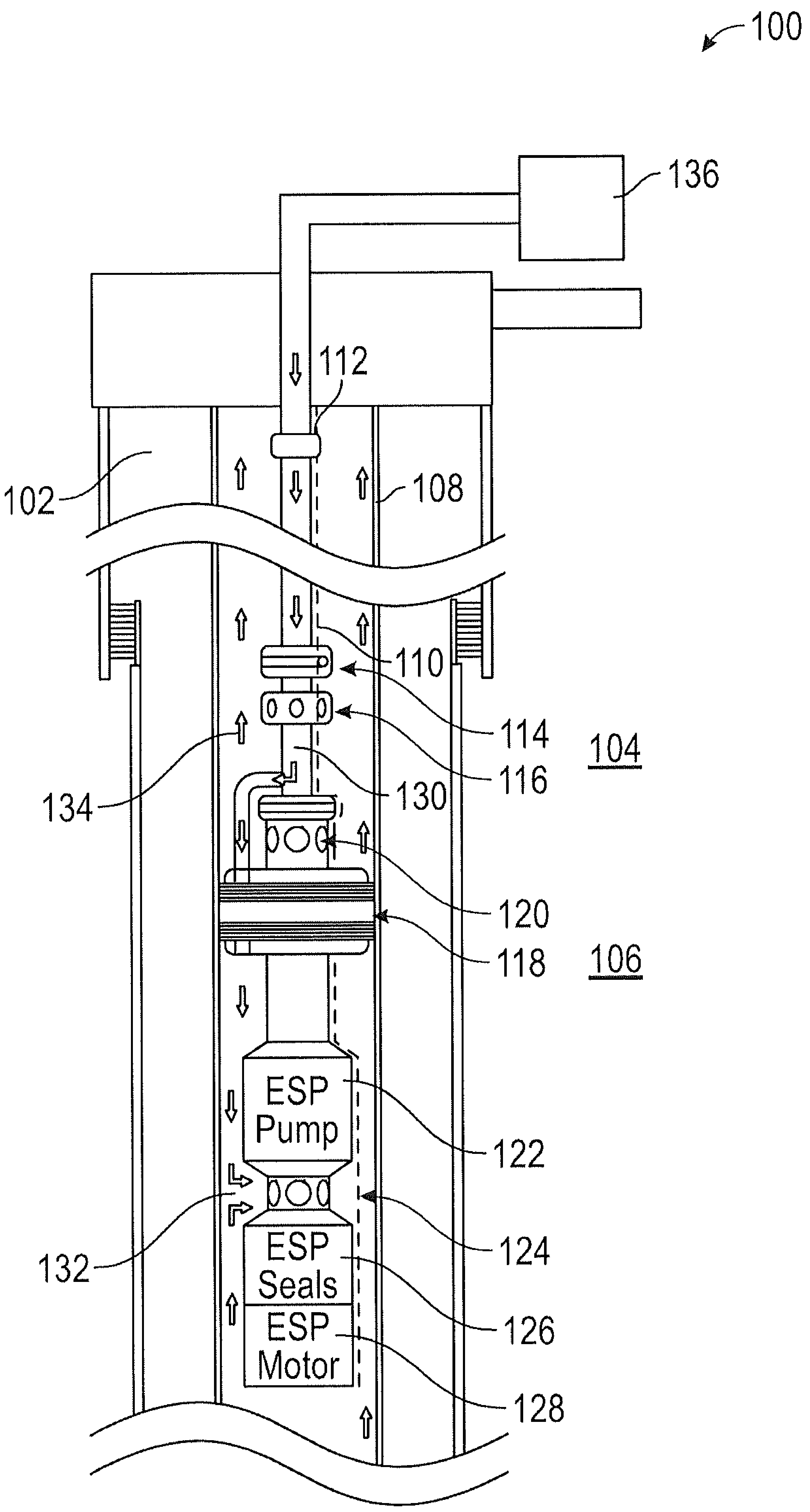

100
136
112
102
108
110
114
104
116
134
130
120
118
106
ESP Pump
122
124
132
ESP Seals
126
ESP Motor
128

FIG. 1

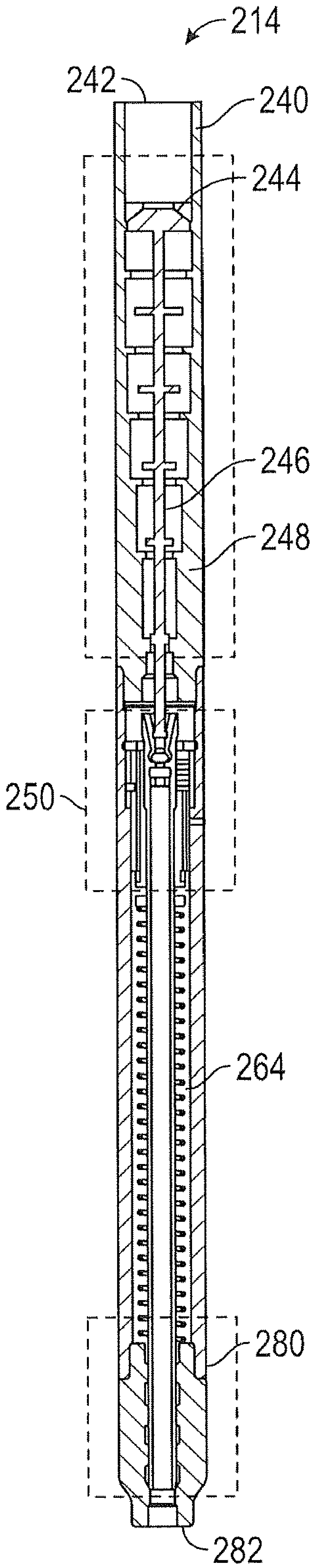

214
242
240
244
246
248
250
264
280
282

FIG. 2A

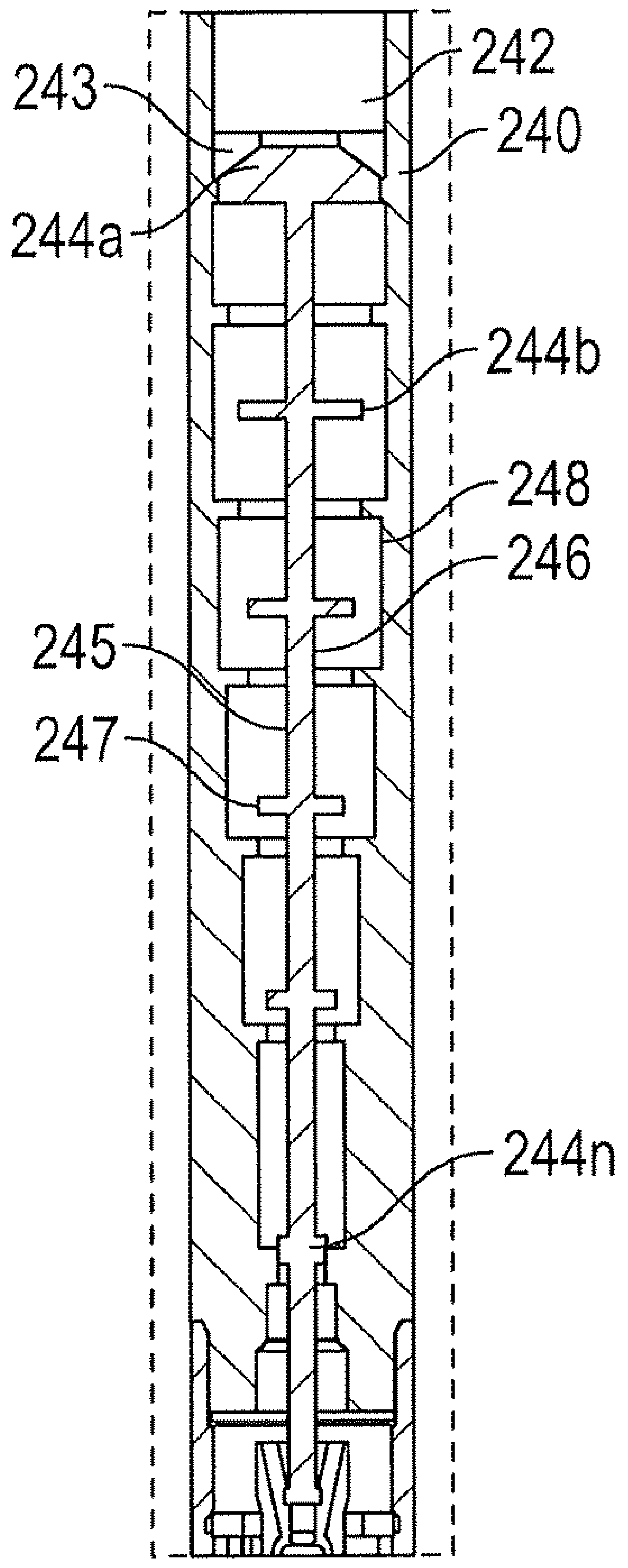

242
243
240
244a
244b
248
246
245
247
244n

FIG. 2B

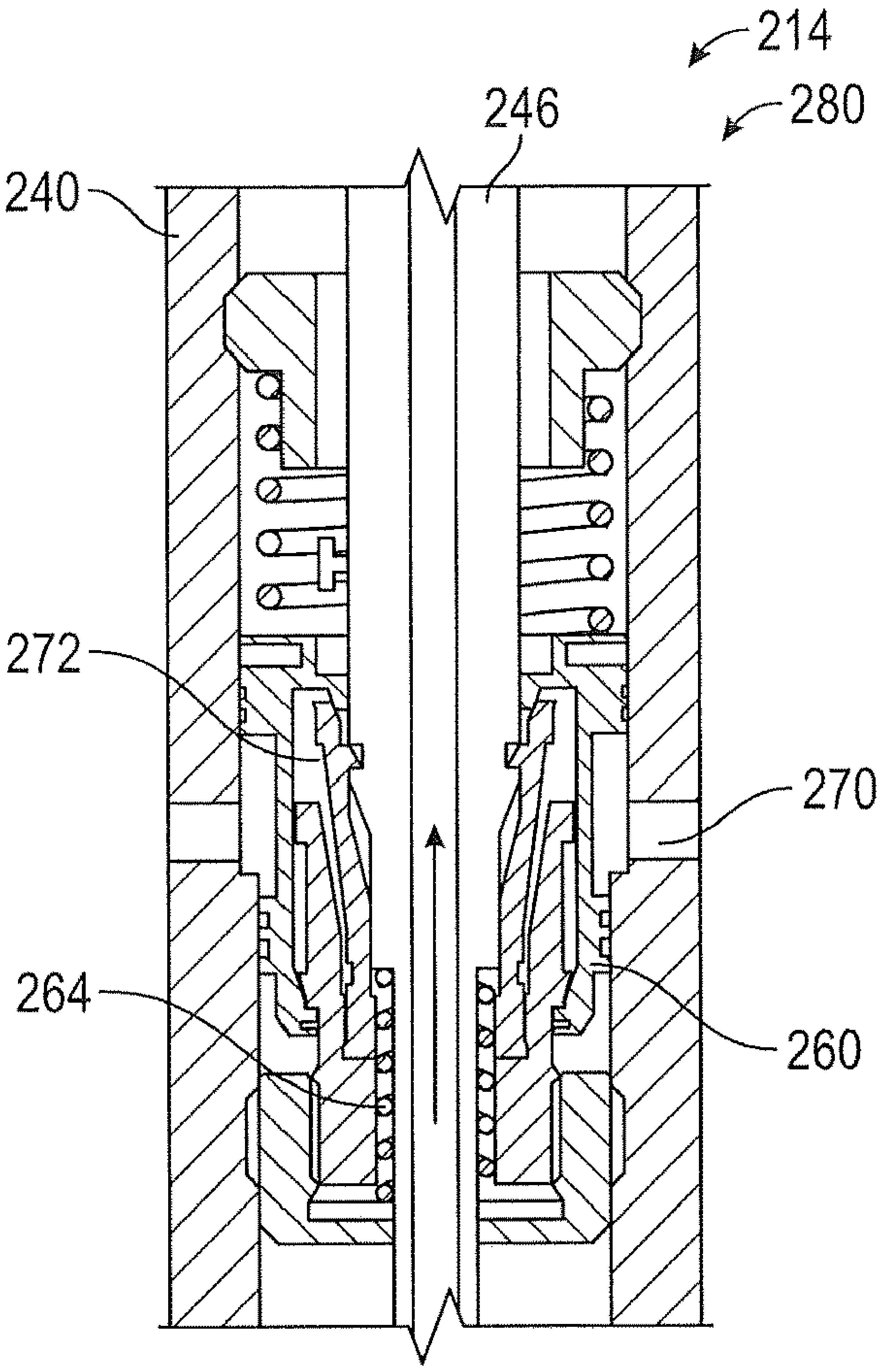


FIG. 2C

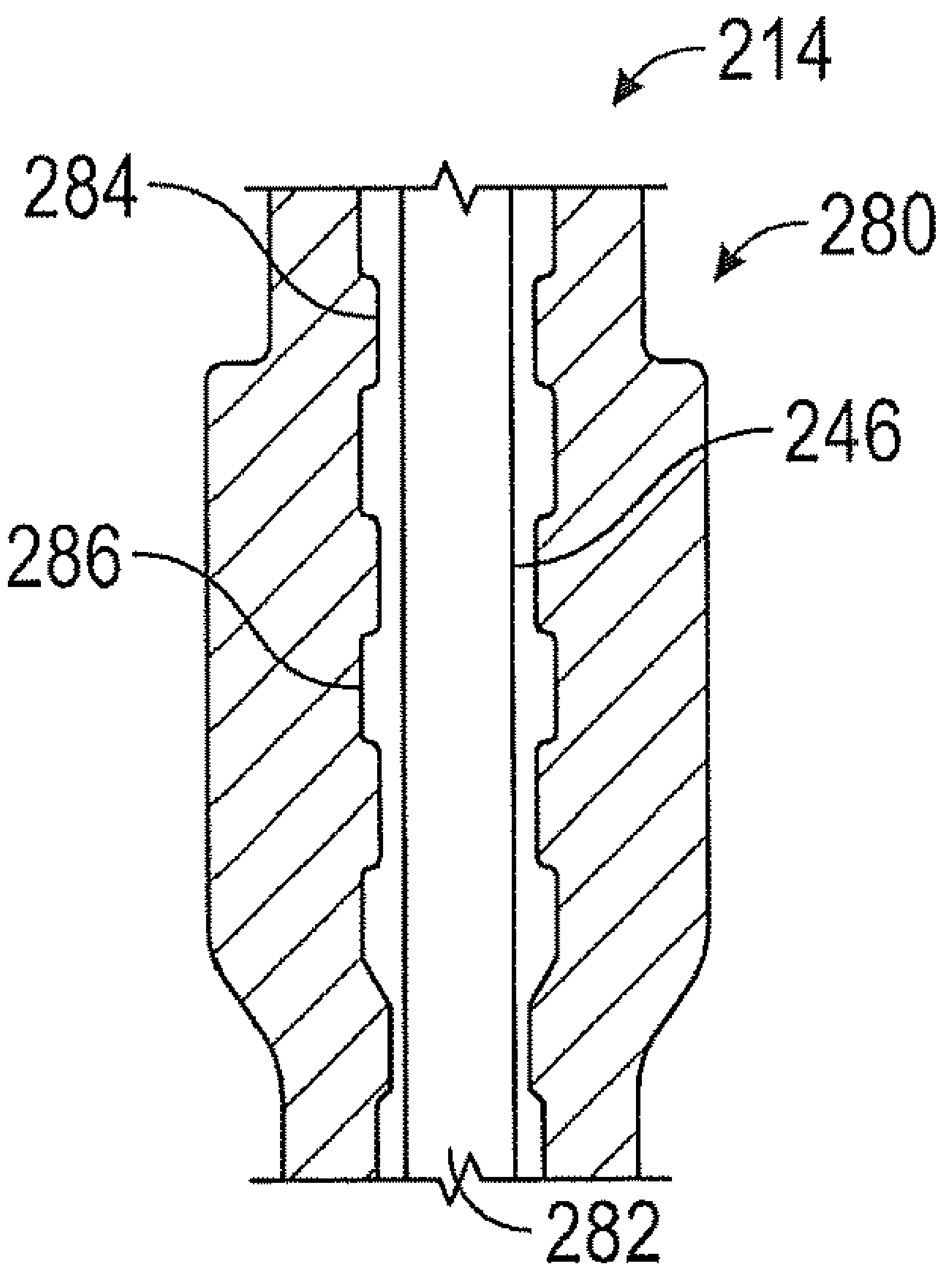


FIG. 2D

PRESSURE DIFFERENTIAL DEVICE WITH CONSTANT PRESSURE DROP

BACKGROUND

1. Field of the Disclosure

This disclosure relates generally to pressure differential devices that facilitate constant pressure differentials across a range of flow rates.

2. Background

Wellbores are drilled in subsurface formations for the production of hydrocarbons (oil and gas). During wellbore operations it is often desired to inject chemicals to downhole locations to prevent corrosion, remove debris, facilitate production, etc. Chemical pumps may experience pump surges due to change in backpressure and other conditions, decreasing pump lifecycle. During chemical injection operations, it is often desired to maintain a constant backpressure for the chemical inlet flow, particularly across flow rates.

The disclosure herein provides a pressure differential device that facilitates constant pressure differentials across a range of flow rates.

SUMMARY

In one aspect, an apparatus for use in a wellbore is disclosed, including: an inlet; an outlet; and a variable flow restriction configured to provide a predetermined constant pressure drop between the inlet and the outlet in response to a range of inlet flow rates.

In another aspect, a system for use in a wellbore is disclosed, including a pump with a fluid flow, a tubular associated with the fluid flow; and a pressure differential device associated with the tubular including: an inlet associated with the fluid flow; an outlet; and a variable flow restriction configured to provide a predetermined constant pressure drop between the inlet and the outlet in response to a range of inlet flow rates.

In another aspect, a method for providing a fluid flow within a wellbore is disclosed, including: providing the fluid flow to an inlet; restricting the fluid flow to provide a predetermined constant pressure drop between the inlet and an outlet in response to a range of fluid flow rates; and providing the fluid flow to the wellbore from the outlet.

Examples of the more important features of certain embodiments and methods have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features that will be described hereinafter and which will form the subject of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed understanding of the apparatus and methods disclosed herein, reference should be made to the accompanying drawings and the detailed description thereof, wherein like elements are generally given same numerals and wherein:

FIG. **1** shows an exemplary wellbore system that includes a pressure differential device, according to one non-limiting embodiment of the disclosure;

FIG. **2**A shows a non-limiting embodiment of a pressure differential device for use in a wellbore system, including the wellbore system shown in FIG. **1**, for deployment in a wellbore, such as wellbore shown in FIG. **1**;

FIG. **2**B shows a partial cross-section view of the pressure differential device shown in FIG. **2**;

FIG. **2**C shows another partial cross-section view of the pressure differential device shown in FIG. **2**; and

FIG. **2**D shows another partial cross-section view of the pressure differential device shown in FIG. **2**.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. **1** is a line diagram of a wellbore system **100** for the production of formation fluids from a well. The assembly **100** is shown to include a casing **108** deployed in wellbore **102** formed in a formation **104**. Tubing **110** is deployed within the casing **108** from a surface location to a downhole location **106**. Chemicals utilized during wellbore operations are supplied into tubing **110**. In an exemplary embodiment, tubing **110** supplies a chemical fluid flow **130** from pump **136** to a downhole location **106**.

Tubing string **110** may include an orienting sub **112** and tubing disconnect **116**. In an exemplary embodiment, tubing string **110** is associated with an electrical submersible pump **122** to facilitate production of formation fluids. In certain embodiments, tubing string **110** is associated with electrical submersible pump **122** via tubing disconnect **116**. Packer **118** may be set to isolate a production zone from other portions of formation **104**.

In an exemplary embodiment, chemical fluid flow **130** passes through packer **118** to be received in a production zone where ESP (electrical submersible pump) pump **122** is located. In other embodiments, chemical fluid flow **130** flows to a general downhole location **106**. Such chemicals may include anti-corrosive chemicals, chemicals to remove debris, diluents, etc. In an exemplary embodiment, chemical fluid flow **130** includes diluent to mix with formation fluid to allow for a lower viscosity flow of formation fluid **134** to facilitate efficient pumping of formation fluid **134** to the surface via ESP pump **122**. The use of diluent allows more efficiency in lifting operations and creates a more desirable resulting product. The ESP system includes ESP pump **122**, ESP cable **124**, ESP seals **126** and ESP motor **128**. The ESP pump **122** receives formation fluid flow **134** and chemical flow **130** at an ESP inlet **132**. Chemical flow **130** may interact with formation fluid flow **134** to allow for the formation fluid flow **134** to be pumped. ESP discharge **120** allows for formation fluid flow **134** to be returned to the surface.

As chemical flow **130** is pumped from the surface the chemical flow **130** rate may vary. In order to provide a constant back pressure as flow rates vary pressure differential device **114** is utilized to facilitate a backpressure within tubing **110** and against pump **136**. A non-limiting embodiment of a pressure differential device **114** is described in reference to FIGS. **2**A-**2**D.

FIGS. **2**A-**2**D shows a non-limiting embodiment of a pressure differential device for use in a wellbore system, including the wellbore system shown in FIG. **1**, for deployment in a wellbore, such as wellbore shown in FIG. **1**. The pressure differential device **214** includes a body **240**, an uphole connection or inlet **242** to receive flow from tubing **110** and an outlet **282**. In an exemplary embodiment, pressure differential device **214** includes disks **244** disposed within bores **248**, connected by a shaft **246**, wherein the shaft **246** is urged by power spring **264**. Pressure differential device **214** further includes a locking mechanism **250** and a damping mechanism **280**.

Referring now to FIG. **2**B, a partial cross sectional view of the pressure differential device **214** is shown. The chemical flow **130** is received in inlet **242**. The pressure differential device includes a variable flow restriction between the inlet and outlet. In an exemplary embodiment, the variable flow restriction is configured to provide a constant pressure drop between the inlet and outlet in response to a range of inlet flow rates. In certain embodiments the range of inlet flow rates include between 10-100 gallons per minute, while in other embodiments the range may include lower or higher flow rates, or larger or smaller ranges of flow rates.

In an exemplary embodiment, a plurality of disks **244*a*-244*n*** are disposed within a plurality of bores **248** to create a plurality of flow restrictions. In an exemplary embodiment, the disks **244*a*-244*n*** are mechanically coupled via shaft **246** that allows the disks **244*a*-244*n*** to move together. Accordingly, the disks **244*a*-244*n*** may cooperatively provide a constant pressure drop across device **214** for a range of flow rates.

In an exemplary embodiment, disks **244*a*-244*n*** are arranged to have decreasing outside diameters as flow **130** flows from an inlet **242** to an outlet **282**. Accordingly, a first disk **244*a*** may have the largest outside diameter while a last disk **244*n*** may have the smallest outside diameter.

Disks **244*a*-244*n*** are disposed within bores **248** to cooperatively provide flow restrictions. Each bore **248** includes a bore inlet **245** and a bore outlet **247** wherein disks **244*a*-244*n*** may translate therebetween. In an exemplary embodiment, the bores **248** are configured wherein the bores **248** housing larger disks **244*a*-244*n*** have a respective larger bore inner diameter. Further, in certain embodiments, the bores **248** are configured to provide a larger difference in diameter between the outside diameter of disks **244*a*-244*n*** and the inner diameter of bores **248** for larger disks **244*a*-244*n***. For example, the difference between the outside diameter of disk **244*a*** and respective inner diameter of bore **248** is larger than the difference between the outside diameter of disk **244*n*** and inner diameter of respective bore **248**.

In an exemplary embodiment, disks **244*a*-244*n*** are upwardly urged by a power spring **264**. Power spring **264** may impart force upon shaft **246** to provide a desired flow restriction in response to a fluid flow. The force of power spring **264** may be selected in response to several design parameters. In an exemplary embodiment, upper disk **244*a*** is urged upward to have a sealing relationship with an inlet interface **243** of its respective bore **248** during a no flow condition.

In order to determine the desired design parameters of disks **244*a*-244*n***, respective bores **248**, and the relative position of disks **244*a*-244*n*** along shaft **246**, the desired operating parameters are analyzed and correlated to the design parameters. First, for each disk **244*a*-244*n*** and respective bore **248** a target flow rate is decided that provides a desired pressure drop at a target flow rate. Next a flow rate range is determined wherein both the minimum and maximum flow rates generate a similar relative error based on the design calculation. This correlation may contemplate bore **248** inner diameter, disk **244*a*-244*n*** outer diameter, fluid density, flow rate, etc.

The pressure drop from each disk **244*a*-244*n*** and respective bore is estimated from annular orifice correlation and the respective pressure drops are added to get a total pressure drop across pressure differential device **214**. Accordingly, the design dimensions are iteratively modified as necessary to achieve the desired pressure drop across a desired flow rate range for pressure differential device **214**. Table 1 below lists an exemplary flow rate range and target flow rate for an exemplary embodiment of differential device **214** including 6 disks.

TABLE 1

	Min Rate (gpm)	Max Rate (gpm)	Target Flow Rate (gpm)
Position 1	10	14.4	12
Position 2	14.4	20.8	17.3
Position 3	20.8	30	25
Position 4	30	43.3	36
Position 5	43.3	62.4	52
Position 6	62.4	90	75

Table 2 below lists an exemplary pressure drop in response to several flow rates for an exemplary embodiment of differential device **214** including 6 disks. As shown, the embodiments described maintain a generally constant pressure drop at various target flow rates by utilizing the plurality of disks **244-244*n***.

TABLE 2

Flow Rate	ΔP (psi)					
(gpm)	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	Disk 6
12	532.125	0.589	0.0726	0.03	0.027	0.038
17.3	1.11	546.38	0.151	0.0618	0.056	0.079
25	2.32	4.06	564.768	0.129	0.117	0.263
36	4.84	5.296	0.654	572.602	0.242	0.343
52	10.04	11.05	1.36	0.559	554.63	0.716
75	20.88	22.988	2.837	1.162	1.051	565.659
Total ΔP (psi)	571.285	590.363	569.8426	574.5438	556.123	567.098

In an exemplary embodiment, at each target flow rate, one disk **244*a*-244*n*** and a respective bore **248** are designed to provide a significant portion of the primary pressure drop. In certain embodiments, one disk **244*a*-244*n*** and a respective bore **248** are designed to provide a target pressure drop at a respective flow rate. In certain embodiments, the primary pressure drop occurs at the disk **244*a*-244*n*** that has a smallest difference between the outside diameter of disk **244*a*-244*n*** and respective bore **248** due to the position of shaft **246** and power spring **264**.

While an embodiment with 6 disks has been described above, other embodiments may include a greater or fewer number of disks. It may be appreciated that the inclusion of a greater number of adjustable flow restrictions or disks may decrease the overall error with respect to the overall change in pressure.

Advantageously, a constant pressure drop minimizes pump surge due to changes in fluid flow, environmental conditions, fluid properties, etc.

Referring now to FIG. **2C** a partial cross sectional view of the pressure differential device **214** is shown, particularly the locking mechanism **250**. In an exemplary embodiment, locking mechanism **250** is controlled by chemical flow **130**, annular fluid pressure or a combination thereof. Locking mechanism **250** allows for two modes of operation. In an exemplary embodiment, locking mechanism **250** allows for shaft **246** to move freely to be urged by power spring **264** and react to a fluid flow **130** as described above when in an unlocked position. Further, locking mechanism **250** allows for shaft **246** to be placed in a locked position wherein the fluid restrictions described above are minimized to allow high fluid flow rate with minimal pressure drop.

In an exemplary embodiment, shaft **246** is placed in a locked position by being pushed downward by imparting a higher than normal operating flow rate upon disks **244*a*-**

244*n*. It may be appreciated that such a flow rate may be determined by using the analysis provided above and exceeding the designed normal fluid flow rate range. After the shaft **246** is urged downward beyond normal operating position split latch **272** will lock shaft **246** into place. To release the locked shaft **246** annular pressure is applied through port **270** to urge sliding sleeve **260** upward. Accordingly, this releases the split latch **272** and allows shaft **246** and disks **244***a*-**244***n* to move freely as described above.

Referring now to FIG. **2**D a partial cross sectional view of the pressure differential device **214** is shown, particularly the damping mechanism **280**. During operation shaft **246** may move quickly and often in response to fluid flow changes. In order to prevent unwanted oscillations, damping mechanism **280** may filter such movements. In an exemplary embodiment, raised portions **284**, and lower portions **286** in conjunction with a fluid flow **130** may filter oscillations of shaft **246** removing extraneous and transient oscillations.

Therefore in one aspect, the present disclosure provides an apparatus for use in a wellbore, including: an inlet; an outlet; and a variable flow restriction configured to provide a predetermined constant pressure drop between the inlet and the outlet in response to a range of inlet flow rates. In certain embodiments the variable flow restriction is a plurality of associated flow restrictions. In certain embodiments the plurality of associated flow restrictions are mechanically coupled. In certain embodiments the plurality of associated flow restrictions is a plurality of associated disks. In certain embodiments the plurality of associated disks are disposed in a plurality of bores. In certain embodiments each of the plurality of associated flow restrictions is configured to provide a target pressure drop in response to each of a plurality of discrete inlet flow rates. In certain embodiments the variable flow restriction includes a damping mechanism. In certain embodiments the variable flow restriction includes a locking mechanism configured to lock the variable flow restriction in a locked position to provide a minimal flow restriction between the inlet and the outlet.

In another aspect, the present disclosure provides a system for use in a wellbore, including a pump with a fluid flow a tubular associated with the fluid flow; and a pressure differential device associated with the tubular including: an inlet associated with the fluid flow; an outlet; and a variable flow restriction configured to provide a predetermined constant pressure drop between the inlet and the outlet in response to a range of inlet flow rates. In certain embodiments the variable flow restriction is a plurality of associated flow restrictions. In certain embodiments the plurality of associated flow restrictions are mechanically coupled. In certain embodiments the plurality of associated flow restrictions is a plurality of associated disks. In certain embodiments the plurality of associated disks are disposed in a plurality of bores. In certain embodiments each of the plurality of associated flow restrictions is configured to provide a target pressure drop in response to each of a plurality of discrete inlet flow rates. In certain embodiments the variable flow restriction includes a damping mechanism. In certain embodiments the variable flow restriction includes a locking mechanism configured to lock the variable flow restriction in a locked position to provide a minimal flow restriction between the inlet and the outlet.

In another aspect, the present disclosure provides a method for providing a fluid flow within a wellbore, including: providing the fluid flow to an inlet; restricting the fluid flow to provide a predetermined constant pressure drop between the inlet and an outlet in response to a range of fluid flow rates; and providing the fluid flow to the wellbore from the outlet. In certain embodiments, the method includes providing a plurality of associated flow restrictions configured to restrict the fluid flow. In certain embodiments, the method includes mechanically coupling the plurality of associated flow restrictions. In certain embodiments, the method includes providing a target pressure drop via each of the plurality of associated flow restrictions in response to each of a plurality of discrete fluid flow rates.

The invention claimed is:

1. An apparatus for use in a wellbore, comprising:
an apparatus inlet;
an apparatus outlet:
a plurality of bones through which fluid flows between the apparatus inlet and the apparatus outlet, each of the plurality of bores having a bore outlet; and
a plurality of movable members attached along a shaft between the apparatus inlet and apparatus outlet, the plurality of movable members being associated with the plurality of bores, with each movable member being associated with a respective bore, wherein the plurality of movable members are movable to alter a variable flow restriction between the apparatus inlet and apparatus outlet to provide a predetermined constant pressure drop between the apparatus inlet and the apparatus outlet in response to a range of apparatus inlet flow rates, wherein each bore provides a different pressure drop, and a primary pressure drop occurs at the movable member having a smallest difference between an outside diameter of the movable member and its respective bore outlet due to a position of the shaft.

2. The apparatus of claim **1**, wherein the variable flow restriction is a plurality of associated flow restrictions created by the plurality of movable members.

3. The apparatus of claim **2**, wherein each of the plurality of associated flow restrictions is configured to provide a target pressure drop in response to each of a plurality of discrete apparatus inlet flow rates.

4. The apparatus of claim **1**, wherein the plurality of movable members is a plurality of movable disks.

5. The apparatus of claim **1**, wherein the plurality of bores are between the apparatus inlet and the apparatus outlet.

6. The apparatus of claim **1**, wherein the variable flow restriction includes a damping mechanism that urges the plurality of movable members towards the apparatus inlet.

7. The apparatus of claim **1**, further comprising a locking mechanism configured to lock the plurality of movable members in a locked position to provide a minimal flow restriction between the apparatus inlet and the apparatus outlet.

8. A system for use in a wellbore, comprising:
a pump with a fluid flow;
a tubular associated with the fluid flow; and
a pressure differential device associated with the tubular including: a device inlet associated with the fluid flow:
a device outlet;
a plurality of bores through which fluid flows between the device inlet and the device outlet, each of the plurality of bores having a bore outlet; and
a plurality of movable members attached along a shaft between the device inlet and the device outlet, the plurality of movable members being associated with the plurality of bores, with each movable member being associated with a respective bore, wherein the plurality of movable members are movable to alter a variable flow restriction between the device inlet and device outlet to provide a predetermined constant pressure drop between the device inlet and the device outlet

in response to a range of device inlet flow rates, wherein each bore provides a different pressure drop, and a primary pressure drop occurs at the movable member having a smallest difference between an outside diameter of the movable member and its respective bore outlet due to a position of the shaft.

9. The system of claim **8**, wherein the variable flow restriction is a plurality of associated flow restrictions created by the plurality of movable members.

10. The system of claim **9**, wherein each of the plurality of associated flow restrictions is configured to provide a target pressure drop in response to each of a plurality of discrete device inlet flow rates.

11. The system of claim **8**, wherein the plurality of movable members is a plurality of movable disks.

12. The system of claim **8**, wherein the plurality of bores are between the device inlet and the device outlet.

13. The system of claim **8**, wherein the variable flow restriction includes a damping mechanism that urges the plurality of movable members towards the device inlet.

14. The system of claim **8**, wherein the variable flow restriction includes a locking mechanism configured to lock the plurality of movable members in a locked position to provide a minimal flow restriction between the device inlet and the device outlet.

15. A method for providing a fluid flow within a wellbore, comprising:

providing the fluid flow to a device inlet of an pressure differential device having the device inlet and a device outlet;

moving a shaft having plurality of movable members between the device inlet and the device outlet, wherein the plurality of movable members are associated with a plurality of bores with each movable member being associated with a respective bore, wherein moving the shaft moves the plurality of movable members to alter a variable flow restriction between the device inlet and the device outlet to provide a

predetermined constant pressure drop between the device inlet and the device outlet in response to a range of fluid flow rates at the device inlet, wherein each bore provides a different pressure drop, and a primary pressure drop occurs at the movable member having a smallest difference between an outside diameter of the movable member and its respective bore outlet due to a position of the shaft; and

providing the fluid flow to the wellbore from the device outlet.

16. The method of claim **15**, further comprising creating a plurality of associated flow restrictions configured to restrict the fluid flow with the plurality of movable members.

17. The method of claim **16**, further comprising providing a target pressure drop via each of the plurality of associated flow restrictions in response to each of a plurality of discrete fluid flow rates.

* * * * *